BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Tethered LM/ATM Modes for AAP 3/4 Case 600-3

DATE: April 10, 1967

FROM: J. Kranton

ABSTRACT

This memorandum discusses the problems associated with operating the LM/ATM tethered to the Workshop. Various tethered modes are identified and evaluated in an attempt to narrow the field of choice.

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MEMORANDUM FOR FILE

INTRODUCTION

This memorandum discusses the problems associated with operating the LM/ATM tethered to the Workshop. Various tethered modes are identified and evaluated in an attempt to narrow the field of choice.

A summary of this material was presented to C.W. Mathews on March 22, 1967.

CLASSIFICATION OF FLEXIBLE TETHER MODES

Three descriptors are required to define a tethered mode. These are: system attitude, Workshop attitude, and LM/ATM attitude. The term system attitude refers to the attitude of the line between the centers-of-mass of the Workshop and the LM/ATM. The four possible modes of tethered operation are identified on Figure 1 and are illustrated on Figures 2 and 3.

Mode 1 is essentially that which was flown on the Gemini XII mission. A great deal of analysis on the dynamics of this mode has been done at MSC. For the LM/ATM mission, however, this mode is inapplicable since the LM/ATM must be inertially oriented towards the sun.

In Mode 2 the Workshop is gravity-gradient stabilized while the LM/ATM is held inertially oriented toward the sun by the CMG system. Observe that the tether wraps around the LM/ATM once per orbit. Consequently, if the mode is to be useful, means must be devised for coping with this problem. Of particular concern is possible interference of the tether with the solar array on the ATM rack. We shall return to this problem subsequently.

Mode 3 is the same as Mode 2 except that the Workshop is also inertially oriented. This results in the tether wrapping around the Workshop as well as the LM/ATM. The mode therefore seems to have all the disadvantages of Mode 2 and in addition a price must be paid for holding the Workshop inertially oriented. Mode 3 is therefore rejected from further consideration.

In Mode 4 the idea is to hold the system as well as the Workshop and LM/ATM inertially oriented. The motivation for considering this mode is that there is no wrap-up.

Having eliminated Modes 1 and 3 from further consideration, the remainder of this memorandum is devoted to a discussion of Modes 2 and 4.

MODE 2 AND THE WRAP-UP PROBLEM

Two ideas present themselves immediately for coping with the wrap-up problem. The first idea is to mount the entire LM/ATM inside a pair of gimbals and have the tether run from the outer gimbal to the Workshop. The gimbal-enclosed LM/ATM and Workshop would fly as in Mode 1 but the LM/ATM would be inertially oriented inside the gimbals. The gimbal rings would of course have to be large enough to permit clearance around the LM/ATM and its solar array. In view of the size of the gimbals required, this concept seems rather difficult to implement and is therefore set aside.

The second idea for dealing with the wrap-up problem is illustrated in Figure 4. A boom is attached to the LM/ATM and the tether runs from the tip of the boom to the Workshop. The boom is connected to the LM/ATM by a joint which permits orientation of the boom so that it is perpendicular to the orbital plane. A solar orientation of the LM/ATM is maintained by the CMG system. The utility of the boom is displayed in the lower right corner of Figure 4 where we see that the boom must be sufficiently long so that when the tether passes over the LM/ATM it does not interfere with the solar array.

All the technical questions concerning implementation of the boom idea have not been explored as of this writing. However, analyses have been performed[1] which indicate that if proper initial conditions are established the mode is dynamically stable.

An estimate has been made on whether or not the CMG system can counteract the torque on the LM/ATM due to the tension in the tether. The tension in the tether as a function of the Workshop-LM/ATM separation is shown in Figure 5. A

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(1)Hough, W.W. Tether Management Proposals, Bellcomm Technical Memorandum TM-67-1022-1, in preparation.

suitable separation between the two vehicles for safe operation is 100 feet. For such a separation, the tension in the tether is approximately 0.23 lbs. Since the LM/ATM and boom are inertially oriented while the Workshop is tracking the local vertical, the tension in the tether produces a torque vector on the LM/ATM which rotates once per orbit (see Figure 6a). To counteract this torque the CMG system must produce a rotating momentum vector which lags the torque vector by 90° (see Figure 6b). In a circular orbit the magnitude of the required momentum vector is equal to the magnitude of the torque vector divided by the orbital rate.

Figure 7 shows the relation between the required momentum vector and the radial extension of solar array. The solar array as presently planned extends 47.5 ft. or more and would require the CMG system to provide a rotating momentum vector of approximately 9800 ft.lb.sec. The present system cannot meet this requirement since the spin angular momentum of each gyro is only 2000 ft.lb.sec.

The maximum rotating momentum vector the CMG system can provide is between 2000 and 5700 ft.lb.sec. This range of values arises because there are mechanical stops on the inner gimbals of each CMG to prevent gimbal lock. As a result, complete rotation of the maximum momentum vector about certain axes of the spacecraft is precluded. The details of this phenomenon are beyond the scope of this memorandum. The main point is, however, that a taut tether mode forces a constraint on the radial extension of the solar array.

The impact of this constraint is illustrated on Figure 8. Part (a) of the figure shows the 1400 sq.ft. solar array on the LM/ATM as presently planned. In part (b) a possible reconfiguration of the solar array is shown which has the same area but with the radial extension reduced to a point where the CMG system can cope with some taut tether operations. The changes required to the solar array are significant and it seems impractical to consider redesign at this stage of the hardware development of the LM/ATM for AAP 4.

MSFC'S SLACK TETHER MODE

MSFC has under study a slack tether version of Mode 2. The slack tether does not avoid the wrap-up problem and a boom is required on the LM/ATM. However, since the tether is slack, the CMG system does not have to cope with the torque produced by tension in the tether. The disadvantage of the mode is that periodically the relative velocity between the LM/ATM and the Workshop must be adjusted rather precisely by tugging on the tether. The following description of the mode is abstracted from a memorandum by B.S. Perrine, Jr. of MSFC.

Initially the Workshop and LM/ATM are inserted into a near circular orbit. Due to the difference in aerodynamic drag on the Workshop and LM/ATM the separation between the two vehicles changes throughout the orbit. Figure 9 depicts a method by which the two vehicles can be kept in close proximity of one another despite the difference in drag.

At the outset let the Workshop be at perigee with the LM/ATM at the same radius and 30 m. behind the S-IVB but with a differential velocity of .0029 m./sec. greater than the S-IVB. With these conditions the apogee radius, semimajor axis, and period of the LM/ATM orbit are greater than that of the Workshop orbit. After half an orbit, the two vehicles are at apogee with the LM/ATM having fallen behind (due to its increased period) and radially above the Workshop as indicated in Figure 9, position 5. After one complete orbit, the vehicles are back at perigee with the LM/ATM now at position 1. Atmospheric drag has caused its perigee point to fall below the initial perigee point. The apogee radius is also decaying and after two orbital periods, the decay has been sufficient to decrease the semimajor axis of the LM/ATM orbit to be equal to that of the Workshop orbit. After this happens the period of the LM/ATM orbit becomes less than that of the Workshop and the LM/ATM begins to catch up. After 3 1/2 orbits, the LM/ATM apogee radius has decayed to that of the Workshop orbit and the LM/ATM has come to within 22.5 m. of the Workshop. At this time, the tether is reeled taut and an impulse is imparted through it to give the LM/ATM a velocity of .0034 m./sec. greater than the Workshop. This causes the perigee radius, semimajor axis, and period of the LM/ATM orbit to be increased. After four orbits, the LM/ATM is at point 4 and the decay begins again. The initial conditions on position are nearly duplicated after about seven orbits. The initial velocity conditions can be duplicated by another pull on the tether. By repeating this sequence every seven orbits, the two vehicles may be kept within a given separation distance for the duration of the lifetime of the Workshop orbit. It should be noted that the initial differential velocity at perigee is such that the apogee radius will be raised exactly by the amount that it will be decayed during 3 1/2 orbits by the difference in drag. Also, a similar requirement applies to raising the perigee radius when tugging on the tether after 3 1/2 orbits. The choice of making a tug on the tether every 3 1/2 orbits is arbitrary. This could be generalized into making a tug every n + 1/2 orbits.

VARIOUS APPROACHES TO MODE 4

The first idea examined for Mode 4 was to place the Workshop and LM/ATM in congruent elliptical orbits as shown on Figure 10. In such an orbital pattern the separation between vehicles varies between 100 ft (= 2 ea) and 200 ft (= 4 ea). The impracticality of achieving this mode is easily established by noting that for a 250 nm. orbit the required eccentricity is 2.23×10^{-6}, which is equivalent to a difference between the semimajor and semiminor axes of .0007 inch.

The difficulties associated with the foregoing idea leads one to consider the possibility of a rigid tether. An idea for Mode 4 with a rigid tether is illustrated in Figure 11. The LM/ATM is joined to the tether via a rotating joting which, ideally, does not transmit torque. Both vehicles are inertially oriented with a CMG system on the Workshop as well as one on the LM/ATM. The dynamical properties of such a configuration have not been investigated, but the scheme seems feasible.

Placing another CMG system on the Workshop as mentioned above is an unpalatable suggestion for the first LM/ATM mission. Without a CMG system on the Workshop the RCS system on the CSM would be needed for the attitude control job. The RCS fuel required for a 28-day mission would be approximately 5850 lbs. as compared to a maximum extended storage capacity of 3032 lbs. This set of circumstances leads one to inquire into the possibility of flying the Workshop in a quasi-inertial mode which does not require either a CMG system or large amounts of RCS fuel. Such a mode is illustrated on Figure 12.

It can be shown theoretically[(2)] that by appropriately setting the attitude rate of the Workshop, it will oscillate with respect to the inertial orientation and hence its attitude will be quasi-inertial. The tolerances on the attitude rate which must be established are tight and requires the use of rate gyros which are sensitive to .001 deg./sec. as compared to those on the Apollo CMS which are sensitive to .01 deg./sec. It has been estimated that for a 28-day mission approximately 300 lbs. of RCS fuel would be required to maintain the mode. The torque on the LM/ATM due to the forces in the rigid tether imposes a momentum storage requirement of approximately

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(2)Elrod, B.D. Quasi-Inertial Stabilization of AAP 1/2 Cluster Configuration, Bellcomm Technical Report TR-67-600-3-1, in preparation.

2500 ft.lb.sec. which is well within the capability of the CMG system. The quasi-inertial mode, however, is still in the category of an idea since all the technical problems associated with its operation have not been investigated.

SUMMARY AND CONCLUSIONS

Four candidate methods of tethered operation have been identified. These are:

1. Mode 2, with a taut flexible tether: requires a boom on the LM/ATM and a reconfigured solar array.

2. Mode 2, with a slack tether, under study at MSFC: requires a boom on LM/ATM. Periodically the tether must be reeled in and tugged in order to correct the relative velocities between the LM/ATM and the Workshop.

3. Mode 4, with a rigid tether: possible with a CMG system on the Workshop as well as one on the LM/ATM.

4. Quasi-inertial mode with a rigid tether: requires .001 deg./sec. rate gyros as compared to the .01 deg./sec. gyros that are on the Apollo CSM.

Methods 1, 2, and 4 have a common drawback; namely, the tight tolerances on initial attitude rates and relative velocities of the LM/ATM and Workshop. Such problems existed, however, in the tethered flight of Gemini XI and XII and were solved.

ACKNOWLEDGEMENT

The material in this memorandum was developed through the joint efforts of G.M. Anderson, B.D. Elrod, W.W. Hough and the author.

J Kranton

1022-JK-mef J. Kranton

Attachments
Figures 1 through 12

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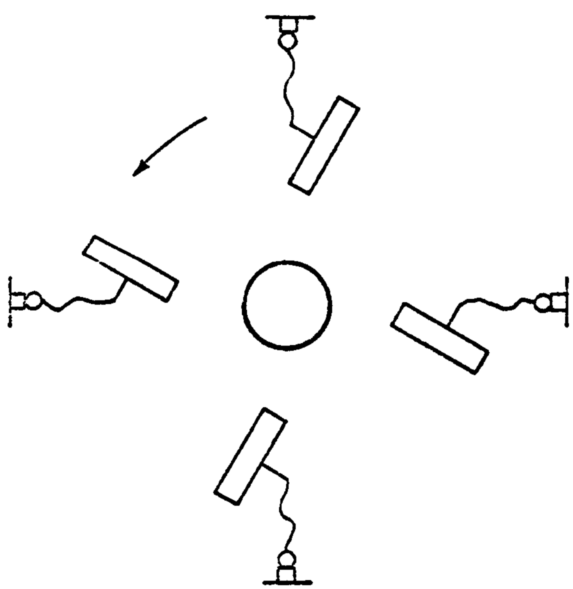
FLEXIBLE TETHER MODES

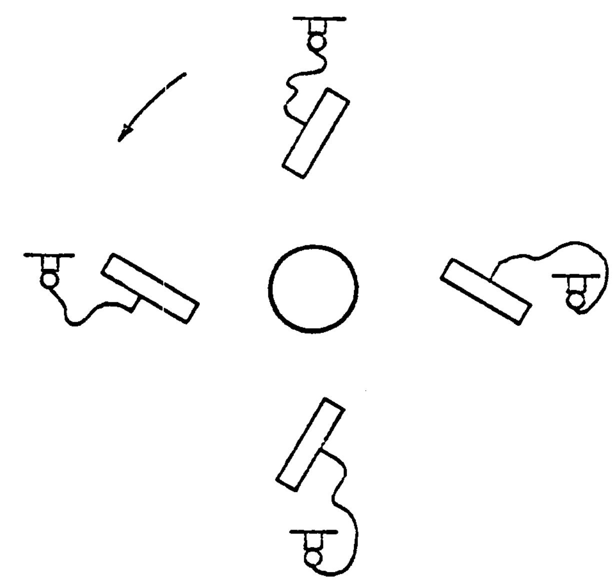
	SYSTEM ATTITUDE	WORKSHOP ATTITUDE	LM ATTITUDE
1.	LOCAL VERTICAL	LOCAL VERTICAL	LOCAL VERTICAL
2.	LOCAL VERTICAL	LOCAL VERTICAL	INERTIAL
3.	LOCAL VERTICAL	INERTIAL	INERTIAL
4.	INERTIAL	INERTIAL	INERTIAL

FIGURE 1

1		2	
SYSTEM	- LV	SYSTEM	- LV
WORKSHOP	- LV	WORKSHOP	- LV
LM	- LV	LM	- INERTIAL



NO WRAP-UP

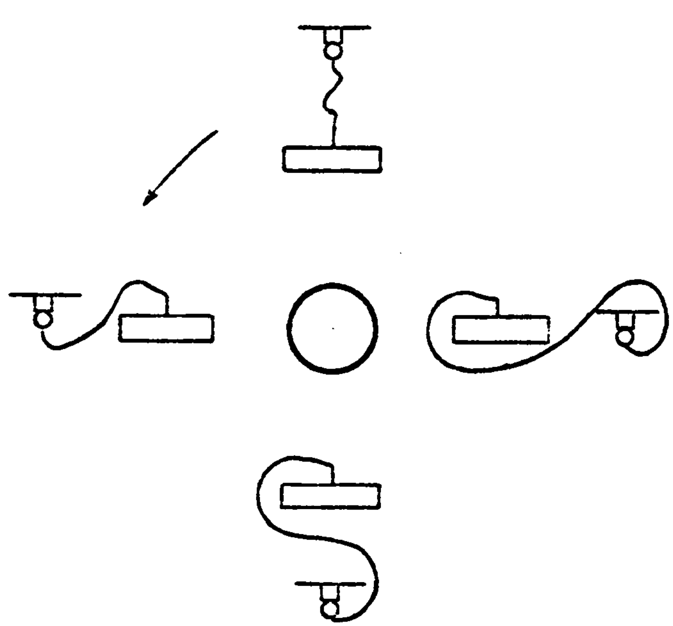


ONE WRAP-UP PER ORBIT

FIGURE 2

3

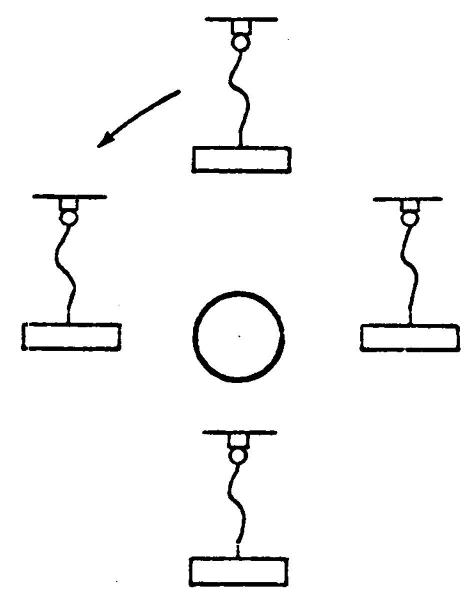
SYSTEM - LV
WORKSHOP - INERTIAL
LM - INERTIAL



TWO WRAP-UPS PER ORBIT

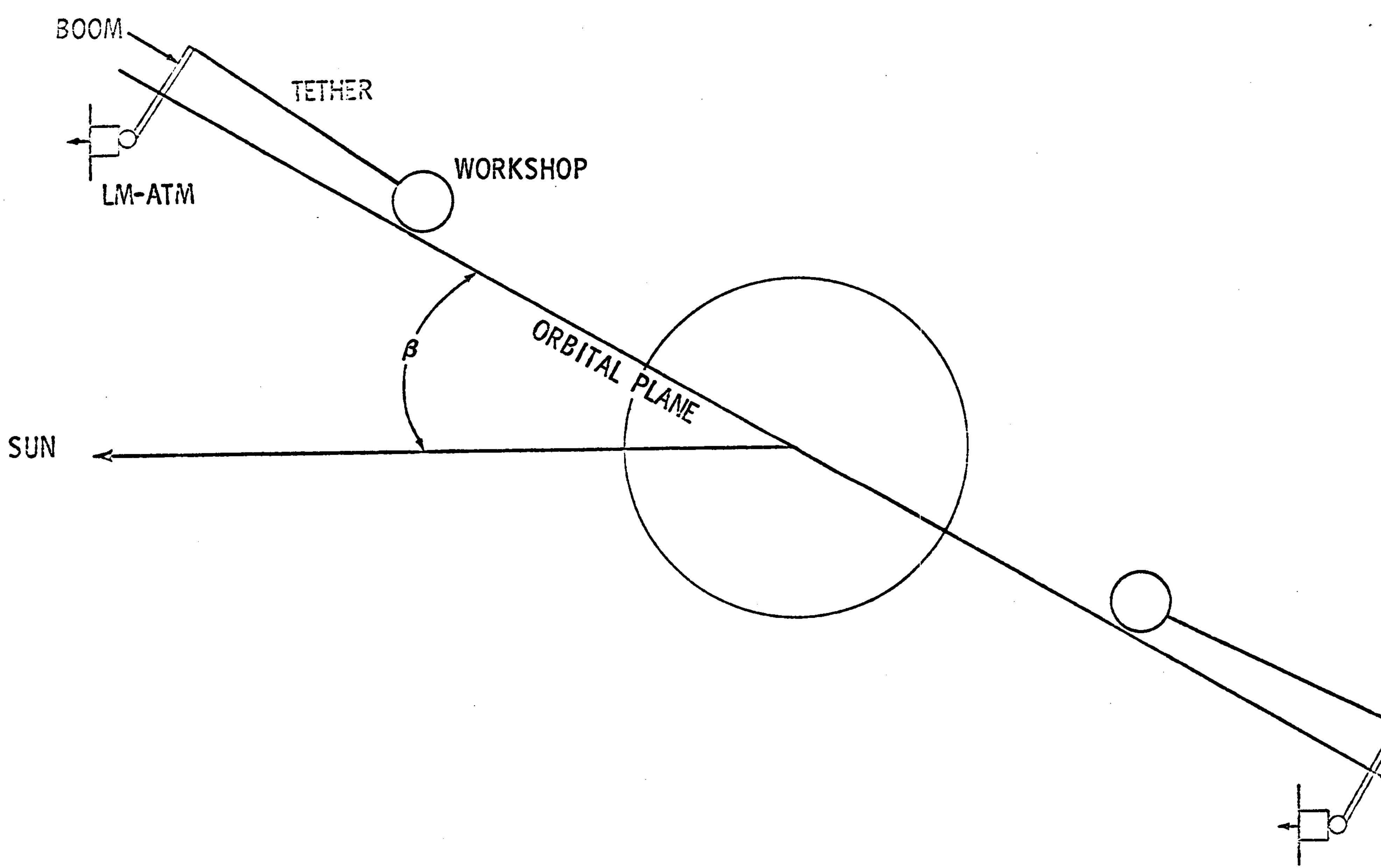
4

SYSTEM - INERTIAL
WORKSHOP - INERTIAL
LM - INERTIAL



NO WRAP-UP

FIGURE 3



EXTENDED BOOM TETHER AVOIDANCE SCHEME

FIGURE 4

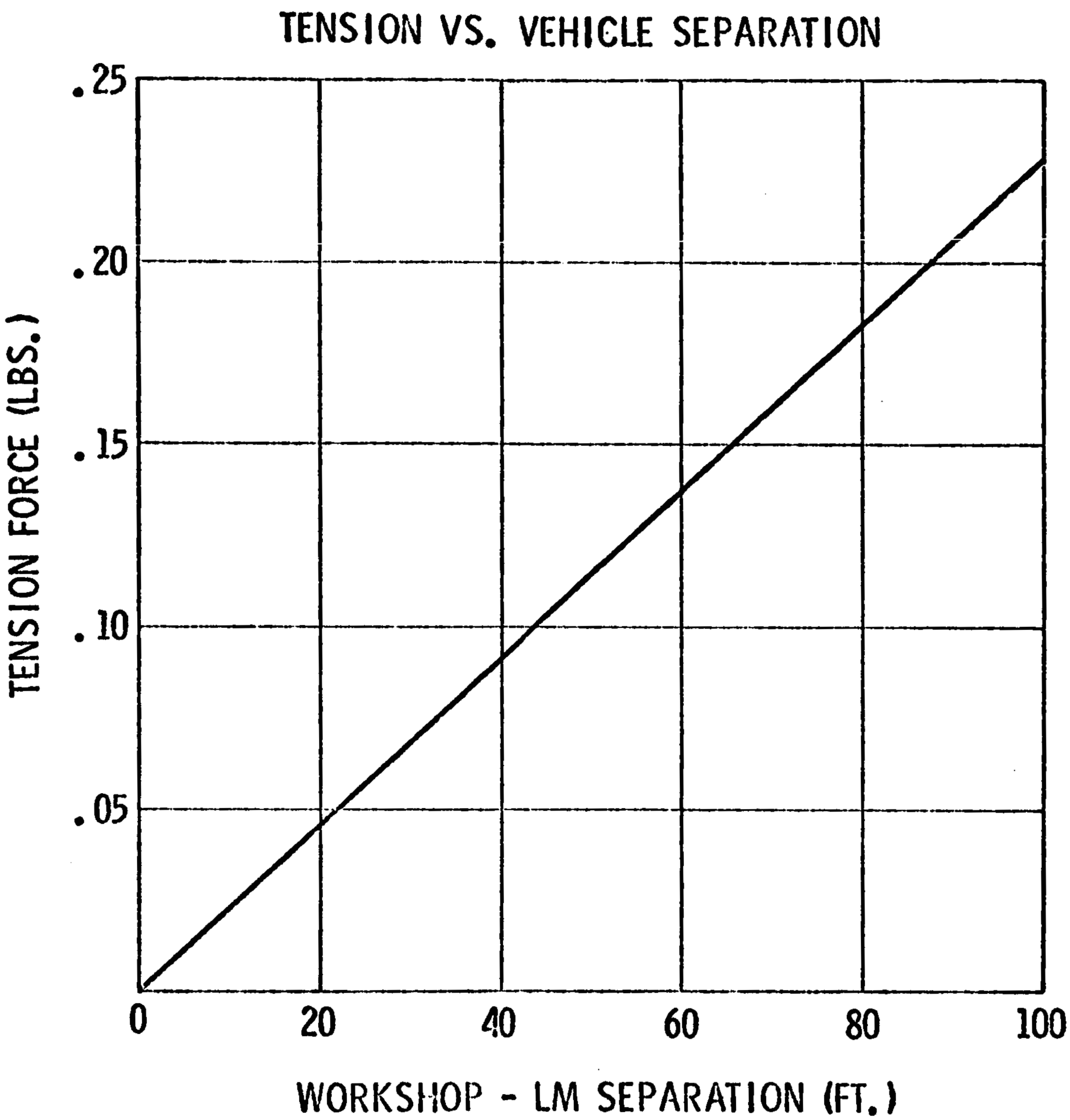

TENSION VS. VEHICLE SEPARATION
TENSION FORCE (LBS.)
.25
.20
.15
.10
.05
0
20
40
60
80
100
WORKSHOP - LM SEPARATION (FT.)

FIGURE 5

TIME PROFILE OF TORQUE AND MOMENTUM VECTORS

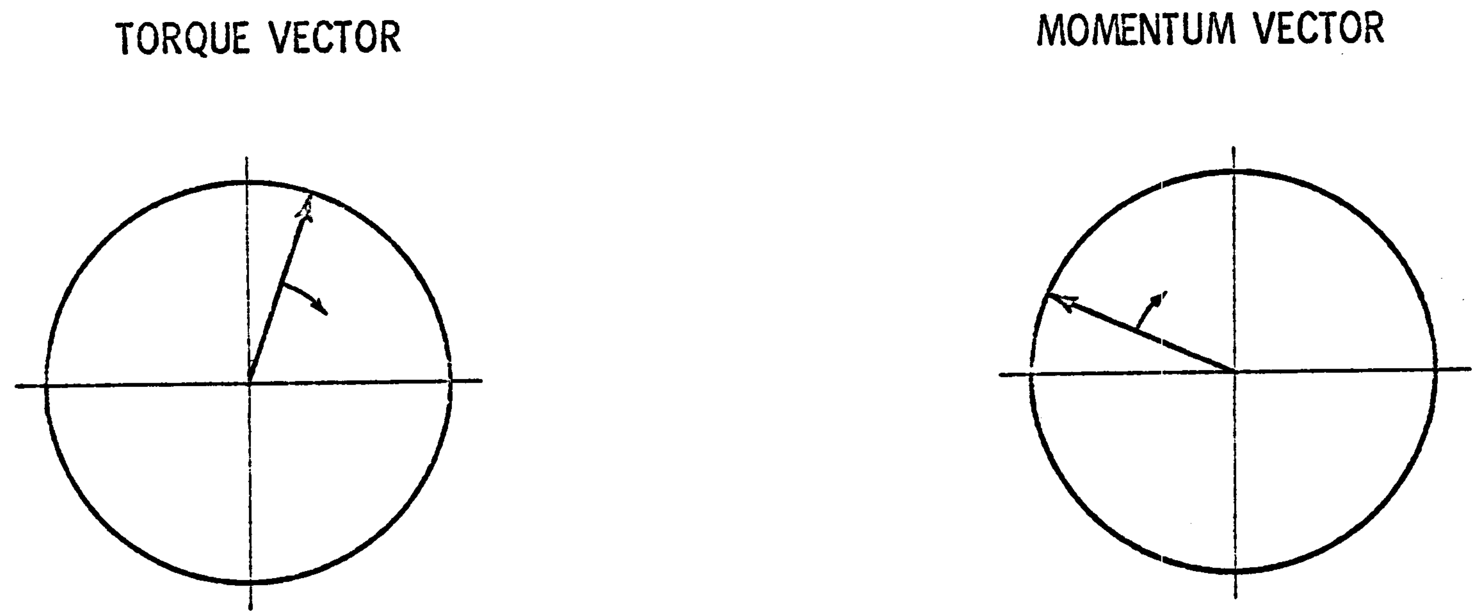


FIGURE 6

REQUIRED MOMENTUM VECTOR VS. SOLAR ARRAY SIZE

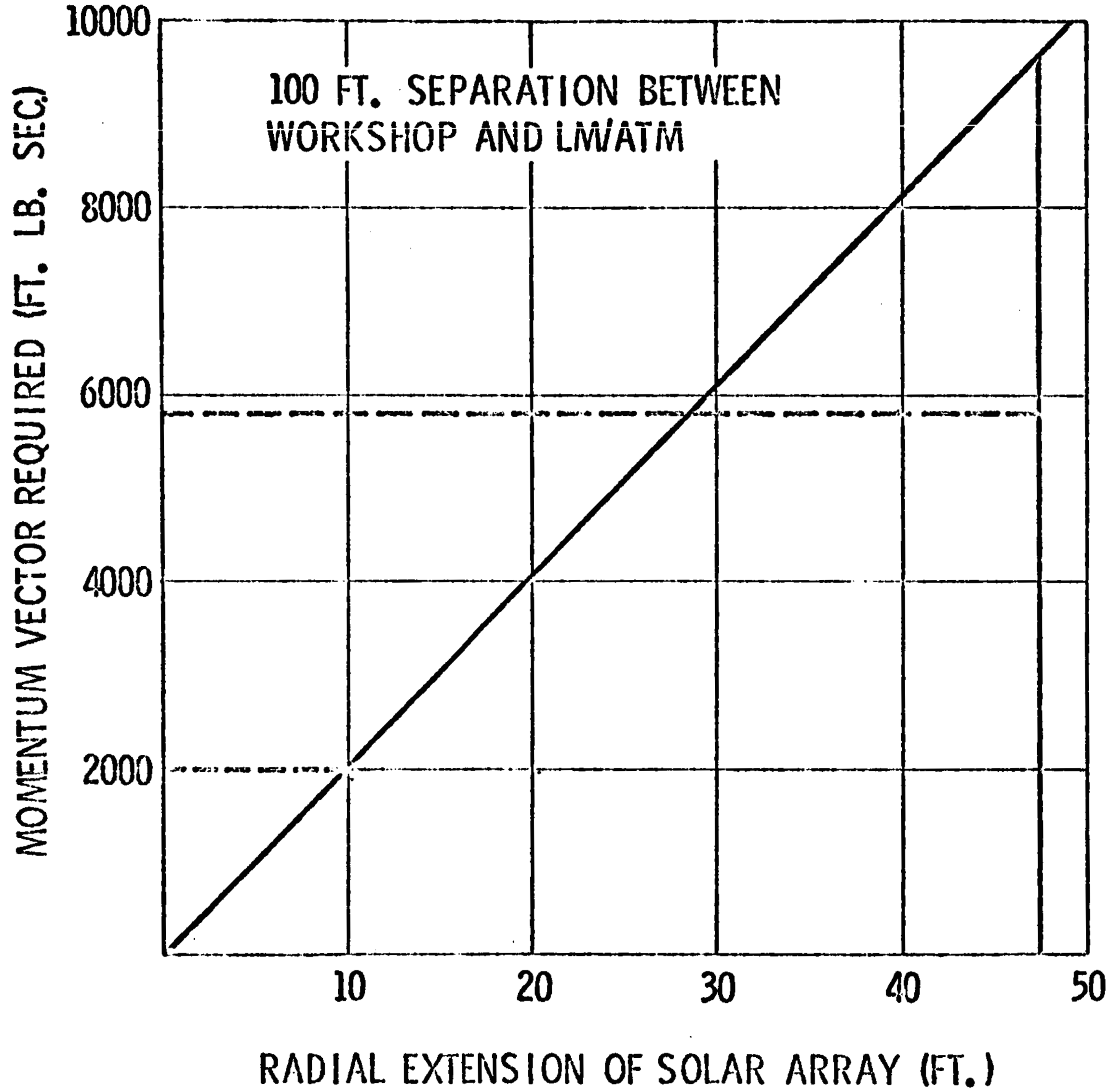
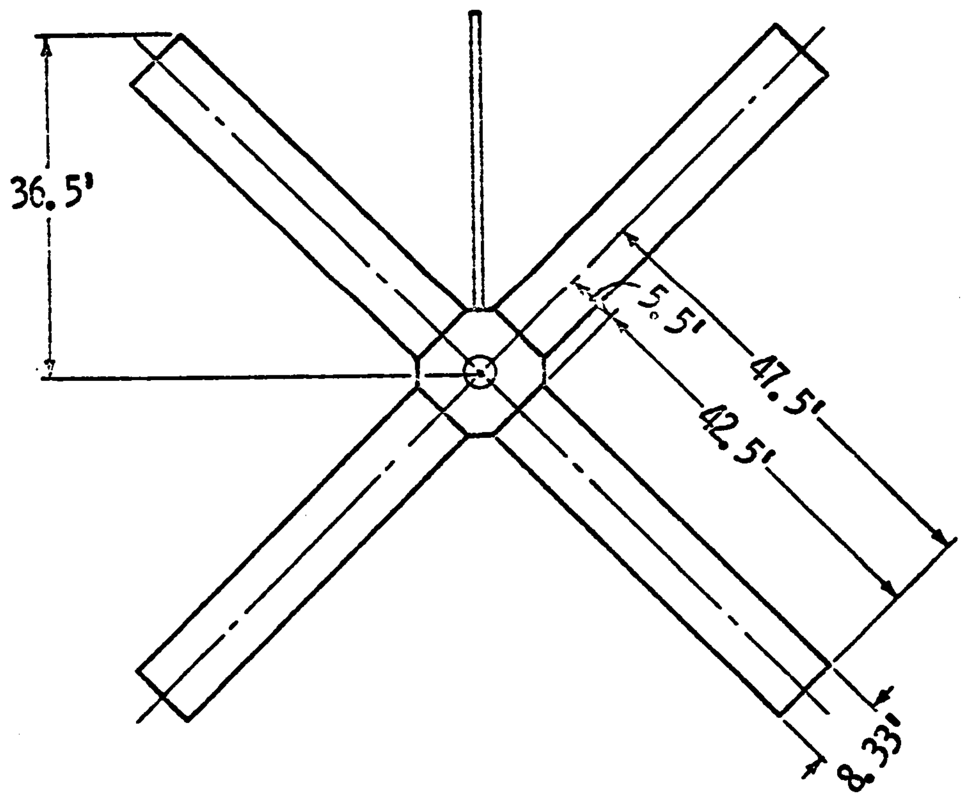
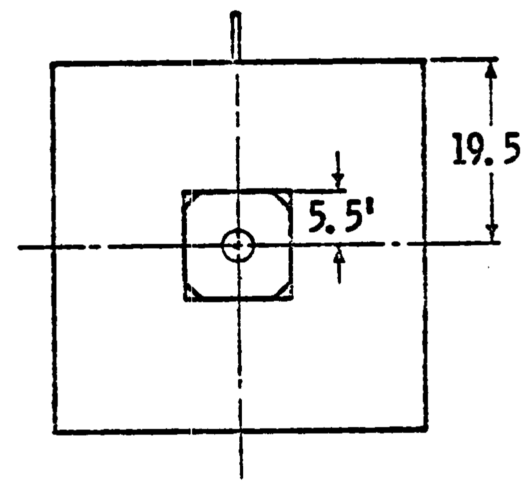


FIGURE 7



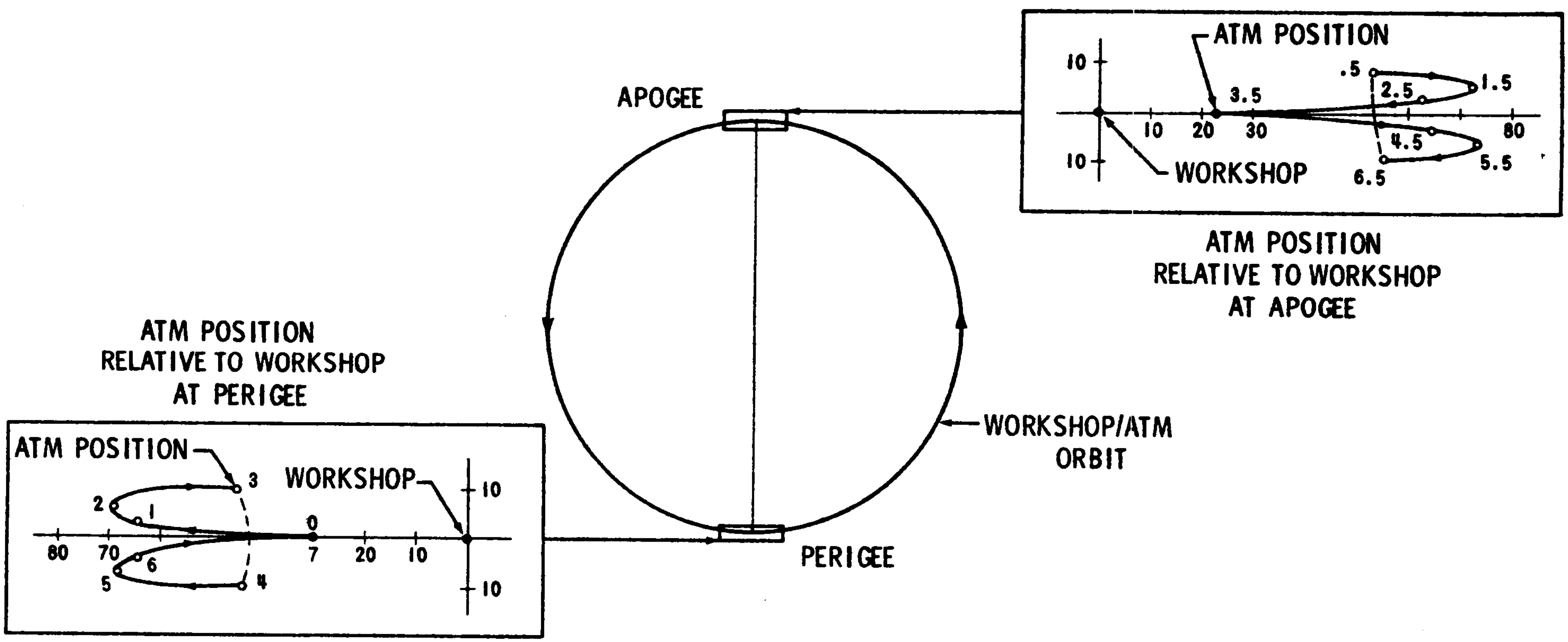
4 SOLAR PANELS, 8.33 x 42.5 = 1400 SQ. FT.
PRESENT CONFIGURATION



PANELS 39 x 39 LESS 11 x 11
IN CENTER = 1400 SQ. FT.

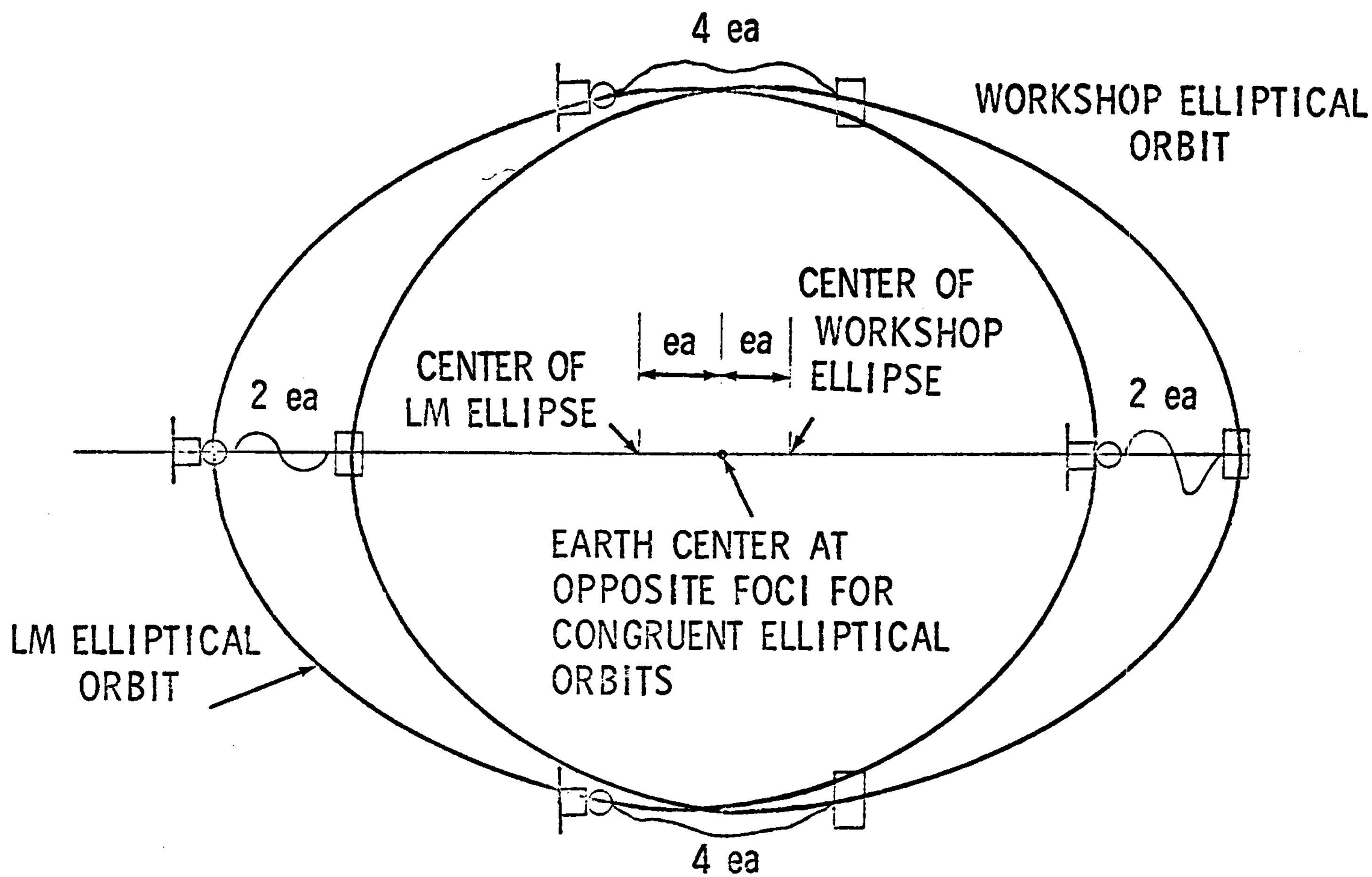
POSSIBLE RECONFIGURATION

FIGURE 8



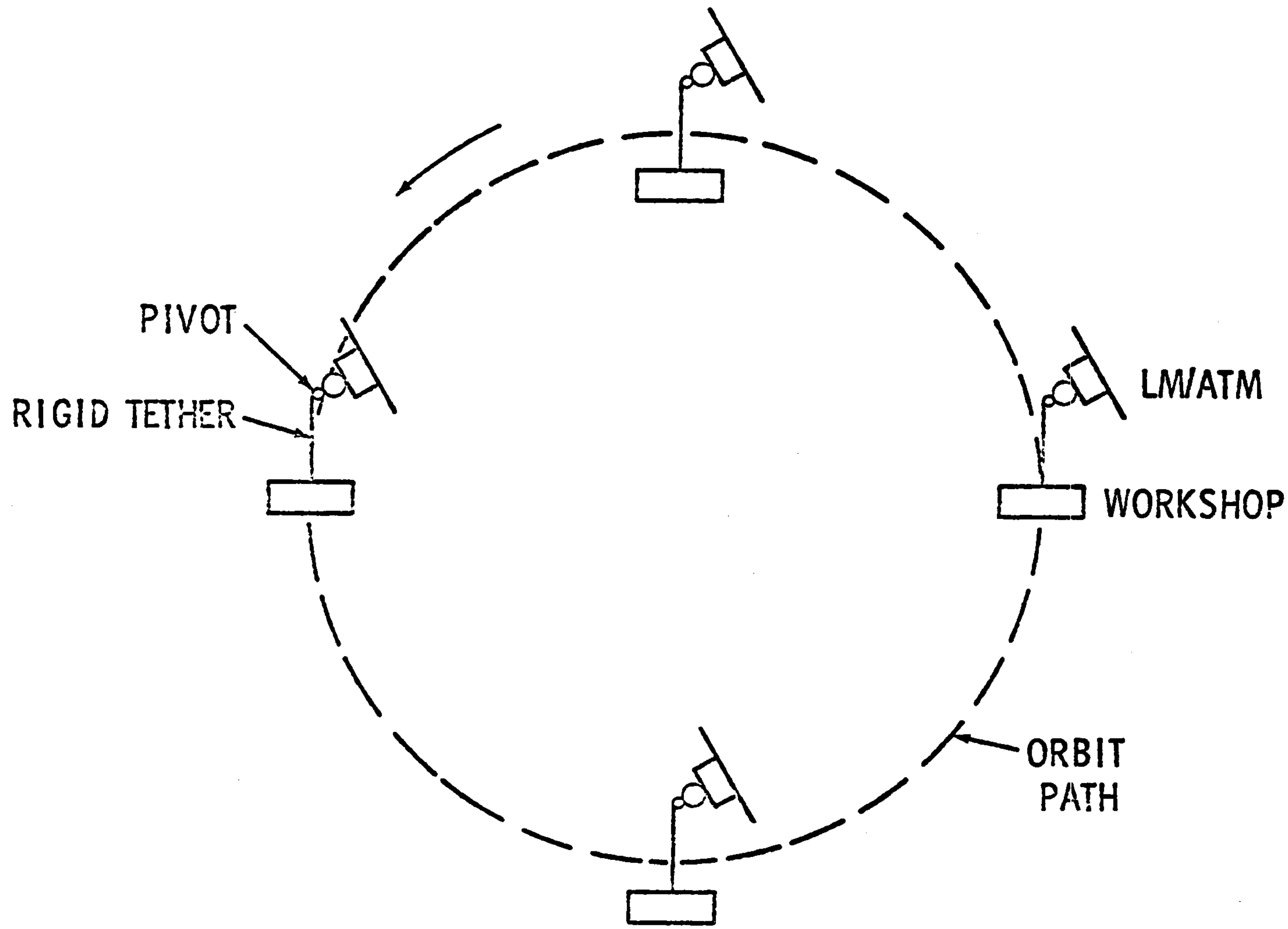
SOFT TETHER STATION KEEPING

FIGURE 9



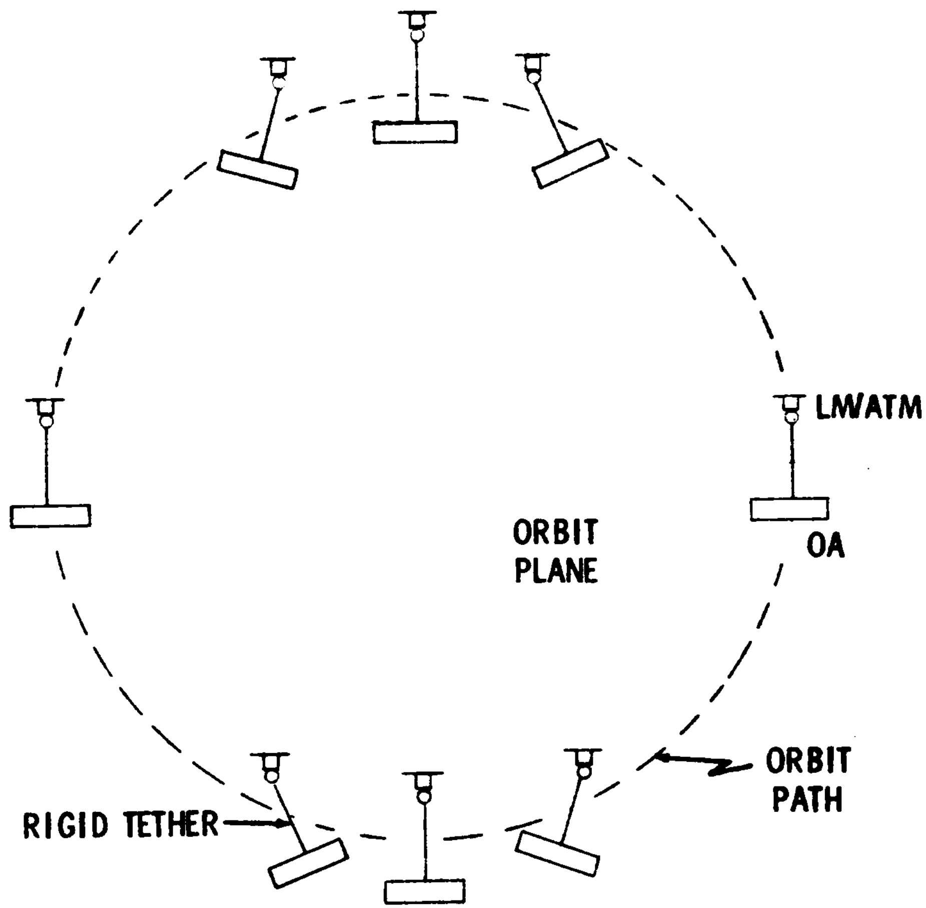
MINIMUM SEPARATION DISTANCE	= 100 FT.
SEMIMAJOR AXIS (a)	= 22.45×10^6 FT.
ECCENTRICITY (e)	= 2.23×10^{-6}
SEMIMINOR AXIS (b) DIFFERS FROM SEMIMAJOR AXIS (a) BY	.0007 INCH

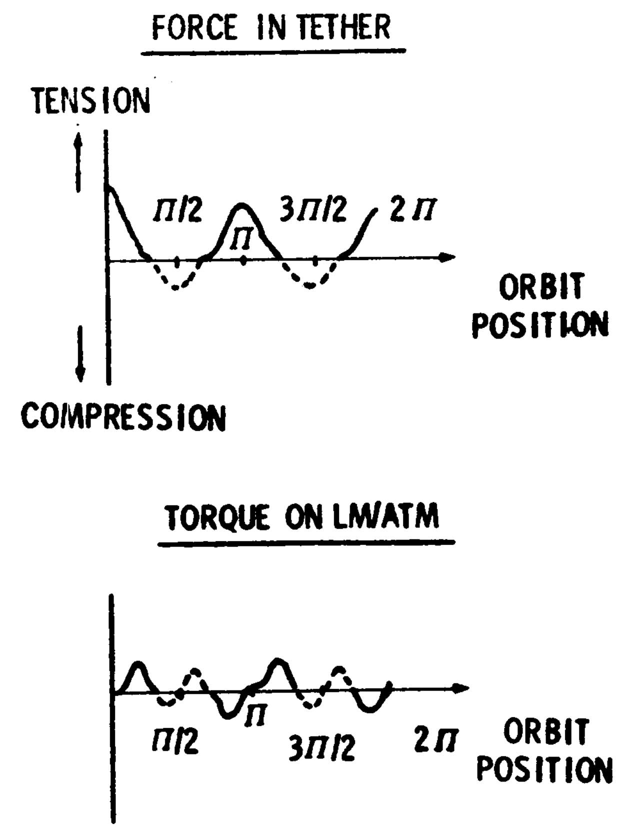
FIGURE 10



ALL-INERTIAL MODE

FIGURE 11





QUASI - INERTIAL MODES

FIGURE 12